Studying Supernova Progenitors with Observations and Simulations

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With increasing numbers of supernovae (SNe) being discovered by survey telescopes, the amount of observational data is rapidly increasing. Most of this data, lightcurves and spectra, provide only indirect information about the progenitor stars and their environments. Comparing simulations to these observations allows us to study the interior composition and other difficult-to-observe properties of the supernova (SN) progenitors. We have used this method to study the recently discovered SN 2012aw and are comparing observations of SN 1987A to our simulations to determine the accuracy of our technique. We are creating a database of simulations that will allow us to more easily match observed supernovae to simulations and derive progenitor and explosion properties.

Supernovae are being observed in increasing numbers, with hundreds discovered each year by a wide array of survey telescopes [1]. Despite the large amounts of data, the information we can derive about the progenitor stars from all of these observations is limited because for most of these SNe we have only lightcurve data, while for some we have spectra as well. Even in the extremely rare cases where the progenitor stars of nearby SNe can be identified on pre-explosion images[2], this only gives a direct measurement of the luminosity and color of the star. The photospheric radius, mass, and temperature of the star can then be inferred–these observations do not give any detail about the interior composition of the star or, except in very extreme cases, its mass loss history. By comparing self-consistent simulations to observed SNe, we can learn more about the composition and size of the progenitor, its mass loss history, and characteristics of the SN explosion itself.

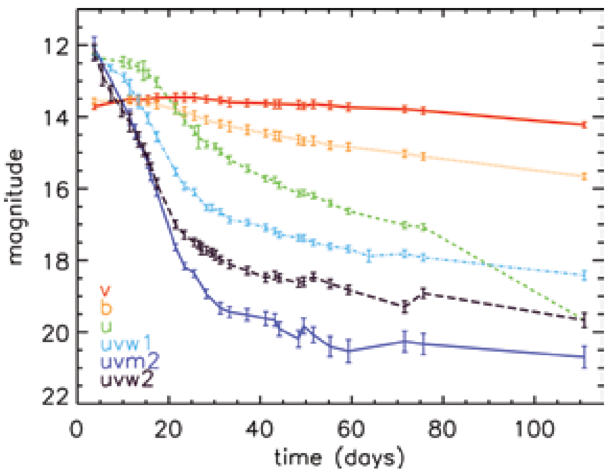

Fig. 1. Observed UV/Optical lightcurve for 2012aw.

One recent SN, 2012aw, was near and bright enough to allow ultraviolet (UV) and optical observations to be made over several months [3,4]. Previous observations of the same region give a constraint of ±0.8 days for the initial explosion time. This means that the explosion time is not a free parameter, as it is for many SNe when the rising phase is not observed and pre-explosion observations do not exist. SN 2012aw was classified as a Type II-P because of the flat plateau observed in the optical lightcurve. It has a UV lightcurve that appears similar to other SNe at early times, but with a flatter slope after about a month (see Fig. 1). Several groups have used pre-explosion images to obtain estimates of the progenitor's properties, giving best estimates of the mass and radius of 15–20 Msun and 1040±100 Rsun [5,6].

We have developed a pipeline to simulate supernovae, beginning with stellar evolution models, simulating core-collapse and then using the rad-hydro code RAGE [7] to follow the evolution of the shock as it propagates outward. We can then calculate spectra at any point after core collapse and integrate over those spectra to create lightcurves for any wavelength band [8].

To learn more about 2012aw and to test the physical accuracy of our new simulation pipeline, we ran a series of simulations and compared their lightcurves to 2012aw. We began with a previously run 2-Msun progenitor that showed similar lightcurve characteristics and modified the wind profile to obtain a closer match. We also tried a smaller 15-Msun progenitor that was intended to be a II-P progenitor, but has a lightcurve that drops off much earlier than that observed for 2012aw. The best fit we have obtained so far is the 23-Msun progenitor, with a mass loss rate of 1e-5 Msun/year and a wind velocity of 1e7 cm/s (see Figs. 2 and 3). The radius of this progenitor is 650 Rsun, smaller than the estimated value for the 2012aw progenitor, so we may obtain a better fit starting with a larger stellar radius.

While comparing our simulations to observed SNe can tell us about the SN being observed, the number of variables involved in the simulations means that it would be easy to obtain similar results with multiple combinations of progenitor properties. To perform a more controlled test of the accuracy of our code, we are beginning a project to match a simulation to SN 1987A. We chose this SN as a test case since it has been very consistently and thoroughly observed since it first exploded, due to its nearby location in a satellite galaxy of the Milky Way, the Large Magellanic Cloud. We will be able to create our progenitor star and the wind environment using known or well-constrained parameters

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and will have many fewer unknowns to adjust. The large amounts of observational data and previously performed analysis will also provide a very comprehensive set for comparisons for both lightcurves and spectra.

The models run for these comparisons to SN2012aw and SN1987A are being used to start a database of SN simulations that will eventually allow future observations to be matched to simulations much more easily. This database will eventually include SN simulations with various combinations of SN type, progenitor mass, metallicity, wind profile, explosion energy, and internal stellar composition (due to different mixing algorithms).

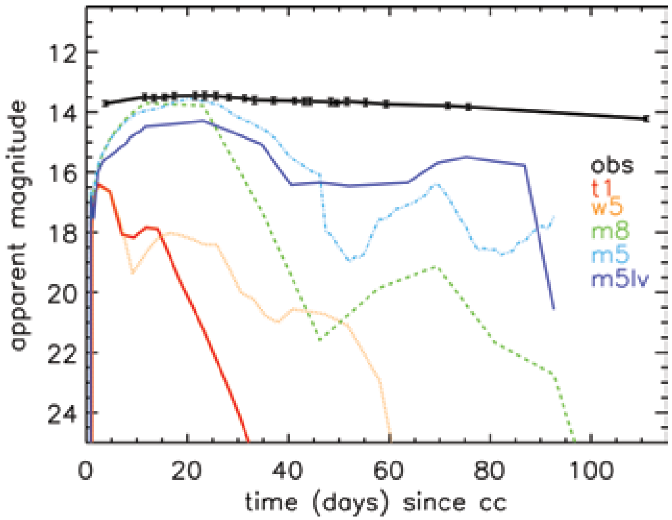

Fig. 2. V-band lightcurve for 2012aw, compared to simulated lightcurves.

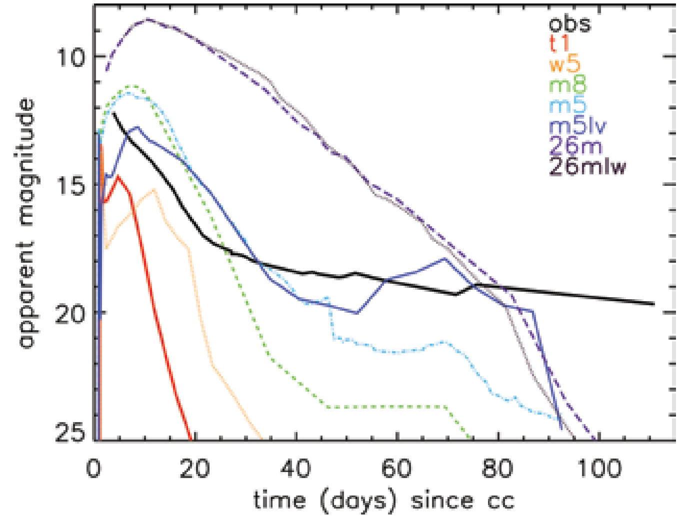

Fig. 3. uvw1-band lightcurve for 2012aw, compared to several simulated lightcurves.

[1] IAU Central Bureau for Astronomical Telegrams, List of Supernovae, http://www.cbat.eps.harvard.edu/lists/Supernovae.html

[2] Smartt, S.J., *Annu Rev Astrpm Astrophys* **47**, 63 (2009).

[3] Fagotti, P., *CBET* **3054**, 1 (2012).

[4] Bayless, A.J. et al., arXiv:1210.5496. (2013).

[5] Van Dyk, S.D. et al., *Astrophys J* **756**, 2 (2012).

[6] Fraser, M. et al., *Astrophys J Letters* **759**, 1 (2012).

[7] Gittings, M. et al., *CS&D* **1**, 015005 (2008).

[8] Frey, L.H. et al., arXiv:1203.5832. (2013).